Dual-Task Obstacle Crossing Training Could Immediately Improve Ability to Control a Complex Motor Task and Cognitive Activity in Chronic Ambulatory Individuals With Spinal Cord Injury

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Background: The effectiveness of dual-task training has been reported in individuals with cognitive impairments. To date, there is no clear evidence on the incorporation of dual-task training in ambulatory individuals with spinal cord injury (SCI) who have intact cognitive functions but have various degrees of sensorimotor dysfunction. **Objectives:** To compare the immediate effects of dual-task obstacle crossing (DTOC) and single-task obstacle crossing (STOC) training on functional and cognitive abilities in chronic ambulatory participants with SCI. **Methods:** This is a randomized 2 × 2 crossover design with blinded assessors. Twenty-two participants were randomly trained using a 30-minute DTOC and STOC training program with a 2-day washout period. Outcomes, including 10-Meter Walk Tests (single- and dual-task tests), percent of Stroop Color and Word Test task errors, Timed Up and Go Test (TUG), and five times sit-to-stand test, were measured immediately before and after each training program. **Results:** Participants showed significant improvement in all outcomes following both training programs ($p < .05$), except percent of Stroop Color and Word Test task errors after STOC training. Obvious differences between the training programs were found for the percent of Stroop task errors and TUG (*ps* = .014 and .06). **Conclusion:** Obstacle crossing is a demanding task, thus the obvious improvement was found immediately after both training programs in participants with long post-injury time (approximately 5 years). However, the findings primarily suggest the superior effects of DTOC over STOC on a complex motor task and cognitive activity. A further randomized control trial incorporating a complex dual-task test is needed to strengthen evidence for the benefit of DTOC for these individuals. **Key words:** *cognition, neurology, physical therapy, rehabilitation, walking*

Everyday activities require the ability to modify movements in response to unpredictable and advancing environments and to successfully conduct a complex and dual-task activity. A dual-task activity (ie, the ability to simultaneously conduct two tasks, generally a physical and a cognitive task) puts a high demand on physical and cognitive functions, particularly for a complex task such as walking or obstacle crossing.[1,2] Such tasks have been used to promote mobility and safety in people with physical and/or cognitive function disorders such as the elderly[3] and patients with stroke,[4,5] Parkinson's disease,[4,6] or Alzheimer's disease.[4]

There has been little evidence on the incorporation of dual-task activities in ambulatory individuals with spinal cord injury (SCI). Although they have intact brain function, sensorimotor deterioration may increase their cognitive or attention demands that affect their ability to efficiently control daily movements. Lajoie et al[7] assessed the ability of six ambulatory participants with SCI and found that the participants allocated significantly greater attentional resources while

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walking than did healthy individuals. A recent study[8] of dual and complex activity found that the increased complexity of the task significantly increased walking time and the percent of cognitive task errors in ambulatory participants with SCI. This evidence was particularly apparent in persons aged 50 years and over with mild lesion severity and who walked with a walking device.[8] However, these attentional requirements were assessed cross-sectionally while participants were walking. Thus the study was unable to confirm the effectiveness of dual-task activity training on the functional and cognitive outcomes of these individuals.

The present study compared the immediate effects of dual-task obstacle crossing (DTOC) and single-task obstacle crossing (STOC) training on functional and cognitive abilities in chronic ambulatory participants with SCI. The findings may suggest the benefit of incorporating dual-task activity training to promote rehabilitation outcomes for these individuals.

Methods

Participants

This study was an assessor-blinded randomized crossover trial in chronic ambulatory participants with SCI (ClinicalTrial.gov ID: NCT02917590) from major tertiary referral and community hospitals. The sample size calculation indicated that each training program required 22 participants. A 10-Meter Walk Test (10MWT) was set as a major outcome of the study, and the study used the magnitude of effect sizes from a recent study[9] ($\mu 1 - \mu 2 = 0.10$, $\sigma = 0.09$, $\alpha = 0.05$, and $\beta = 0.10$). The inclusion criteria were an age of at least 18 years old, a body mass index between 18.50 and 29.90 kg/m^2, and a motor incomplete lesion (American Spinal Injury Association Impairment Scale [AIS] C and D) from trauma or nonprogressive disease with a postinjury time of at least 12 months.[9] The eligible participants also needed the ability to walk independently for over at least 17 meters with or without assistive devices (FIM locomotor scores 5 to 7) and the ability to read Thai. The participants were excluded if they could not complete a training program or had a condition that might affect their participation in the study, such as pain in the musculoskeletal system with a level of pain more than 5 out of 10 on a visual analog scale, deformity in the joints that affected ambulatory ability, or color blindness. The research protocol was approved by the local ethics committee for human research (HE571014). The eligible participants provided a written informed consent document prior to participation in the study.

Intervention

The eligible participants were involved in the study for 5 days. On the first day, they were interviewed and assessed for their personal data and SCI characteristics following the recruitment criteria. On the second day, they were randomly assigned to a DTOC or STOC training program using a concealed envelope and the criteria of age (18-50 years/51-75 years), gender (man/woman), and the requirement of a walking device (yes/no) for training arrangement. Each training program lasted 30 minutes, excluding resting periods. Following the first training session, participants went through a 2-day washout period.[9] Confirmation that carryover effects did not occur was established by Grizzle method[9] and data from 10 pilot cases. On the fifth day, participants were involved in the other training program. Details of the training programs are as follows.

Single-task obstacle crossing training. Obstacle crossing training is an effective challenging activity for ambulatory individuals with SCI.[9] Four obstacles of varying sizes (4 cm wide, 8 cm wide, 4 cm high, and 8 cm high) were randomly placed along a 10-meter walkway at 2-meter intervals (**Figure 1A**). Participants walked at a comfortable speed with or without a walking device according to their usual manner. During the training session, participants were instructed to navigate over the obstacles using their legs and walking device (if any) as continuously as possible.[8,9]

Dual-task obstacle crossing training. Participants were trained using the same protocols as used for the STOC training program while simultaneously performing a Stroop Color and Word Test task (**Figure 1B**). The task required participants to identify the color of as many printed words as possible when there was a mismatch between the meanings of the words and the actual printed colors (eg, the word "green" was printed in

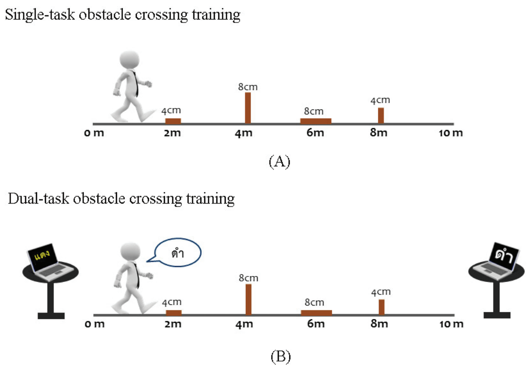

Figure 1. Experimental setup for the training. (A) Single-task obstacle crossing training. (B) Dual-task obstacle crossing training.

blue ink) to the best of their ability.[10] The series of random words was produced using Microsoft Office PowerPoint, printed on a black background, and displayed every 2 seconds on two 14-inch computer notebooks that were mounted at the participants' eye level at both ends of the walkway (**Figure 1B**). This allowed the participants to move only their eyes to see the displayed monitor and obstacles on the floor.[8] This setup challenged the participants to switch, divide, or share attention capacity to control physical and cognitive tasks adequately while executing walking tasks similar to those in daily walking, such as walking up and down stairs or footpath and walking over an electric cord while talking and looking at others.[3]

During training, participants were allowed to use a walking device and take a period of sufficient rest as needed. They wore a lightweight safety belt around their waists, enabling a physiotherapist to assist them if they lost their balance while performing the task. A physiotherapist recorded the total number of trials that the participants could complete within 30 minutes, separately for the success and failure trials, and their causes (ie, either due to physical task [unable to walk over an obstacle] or mental task [Stroop task errors]), resting time, and adverse events that might have occurred during the training.

Outcome measures

Outcomes of the study included the 10MWT while performing the STOC or DTOC, percent of Stroop Color and Word Test task errors, Timed Up and Go Test (TUG), and five times sit-to-stand test (FTSST). They were assessed immediately before and after each training program by a blinded assessor who had excellent reliability in administering the tests (intraclass correlation coefficients [ICCs] = 0.95-0.97).

10-Meter Walk Test. The 10MWT is a valid test with excellent reliability (ICC = 0.994), small standard error of measurement (SEM = 0.05 m/s), and minimal detectable change (MDC = 0.13 m/s) to determine walking ability.[11-14] Outcomes of the test reflect a walking speed that correlates to overall quality of walking and levels of independence of individuals.[11,14] Participants walked at their usual speed with or without a walking device. The time required to cover 4 meters in the middle of the 10-meter walkway was recorded. Then the outcomes were converted to a walking speed using a formula: velocity (m/s) = distance (m)/time (s).[13,15]

Dual-task 10-meter walk test. Outcomes of this test reflect walking performance in a real-life situation.[2] Participants were assessed on the 10MWT while simultaneously performing a task on the Stroop Color and Word Test.[10,16] The outcomes of the test were recorded in terms of walking speed[13-15] and percent of Stroop task errors using the formula: percent of color word Stroop task error (%) = [the number of color word Stroop task errors (times) × 100]/the total number of color word Stroop task (trials).[10]

Timed Up and Go Test. The TUG is a valid and reliable test (ICC = 0.998) with a small range of SEM (0.41 s).[11-14] It is a complex mobility test comprising many sequential locomotor subtasks, including standing up, walking, turning around, and sitting down. Outcomes of the test indicate dynamic balance ability,[12] ability to walk without a walking device,[13] and risk of fall in ambulatory individuals with SCI.[17] The time that participants needed to complete the tasks of rising from a standard armchair, walking for 3 meters, turning around a traffic cone, walking back, and sitting down on the chair at a maximum and safe speed with or without a walking device was recorded.[13,17]

Five times sit-to-stand test. FTSST is a valid test with excellent reliability (ICCs = 0.998) for determining the ability to walk without a walking device (FTSST <14 s, sensitivity = 73%, specificity = 70%).[13,14] Outcomes of the test relate to dynamic balance ability while changing postures and functional lower extremity motor strength.[18,19] Participants were evaluated on the time needed to safely complete five chair-rise cycles as quickly as possible.[13,18]

During the test, participants had a lightweight safety belt fastened around their waists and a blinded assessor beside them to ensure their safety and the accuracy of the test. Each test was repeated for three trials with a period of sufficient rest between the trials and the tests, and the average data were reported.

Analyses

Descriptive statistics were used to describe the demographics of participants and findings of the study. The carryover effects were analyzed using data from 10 pilot cases and the Grizzle method that proceeds in two steps, the first involving the intra-participant sums (S) of the training sequences in which $S_{AB} = X_{1,AB} + X_{2,AB}$ and $S_{BA} = X_{1,BA} + X_{2,BA}$ (where $X_{i,AB}$ denotes the posttest outcomes of the measurement executed in period i [1 or 2] of the participants who completed the interventions in the sequence AB, and $X_{i,BA}$ denotes the same for participants involved in the interventions in the order BA). Then the null hypothesis that $\gamma_A = \gamma_B$ (where γ_A infers the carryover effects of intervention A and γ_B denotes the same for intervention B) was analyzed by comparing the mean sums $S_{AB} = S_{BA}$ using the independent samples *t* test with the level of significance more than 0.10.[9,20] If carryover effects were found, the data from only the first training sequence were used for statistical analyses. However, if there were no carryover effects, the data from both training sequences were included in the data analyses. If the data were normally distributed, the dependent samples *t* test was used to analyze the differences within the training programs, and the independent samples *t* test was applied to assess the differences between the training programs. However, if the data were not normally distributed, the Wilcoxon signed-rank test and Mann-Whitney *U* test were used for the same objectives. A *p* value less than .05 was considered as a level of statistical significance.

Results

Participant characteristics

Twenty-two independent ambulatory participants with SCI completed the training programs (**Figure 2**). Most participants were men (73%) with an average age of 49.81 ± 1.17 (95% confidence interval [95% CI], 44.44-55.17) years old and a post-injury time of 60.86 ± 3.94 (95% CI, 42.89-78.82) months. A large proportion of participants had incomplete paraplegia (95%) and mild lesion severity (AIS D, 77%), with approximately half of them (55%) able to walk independently without a walking device (**Table 1**).

Number of training trials and failure rates during the training

During the 30-minute training, no adverse events occurred in either training program. The participants could complete more STOC training trials than DTOC trials (81.04 ± 40.88 [95% CI, 62.92-99.17] trials for STOC training and 68.18 ± 37.65 [95% CI, 51.48-84.87] trials for DTOC training), with the mean differences between the training programs of 12.86 ± 7.95 (95% CI, 9.33-16.39) trials or 128.60 ± 79.50 (95% CI, 93.40-163.90) meters. The average accumulated resting time during the training was 10.88 ± 4.97 (95% CI, 8.68-13.09) minutes for STOC training and 11.31 ± 4.34 (95% CI, 9.38-13.24) minutes for DTOC training, with a mean difference between the training protocols of 0.43 ± 0.47 (95% CI, -0.69 to 1.36) minutes.

The total number of STOC and DTOC trials completed during 30 minutes for each participant was converted to 100% and divided into four quarters (25%) in order to clearly illustrate the changes of failure rates that occurred during the training programs (**Figure 3**). The findings demonstrated that, when involved in the STOC training, participants were successful in most trials (94%-97%) with rather constant failure rates (legs or walking device contacted with the obstacles on the floor) from the beginning to the end of 30-minute training period (6%-3%; **Figure 3A**). On the contrary, participants in the DTOC training showed high failure rates (49%; **Figure 3A**), particularly due to Stroop task or

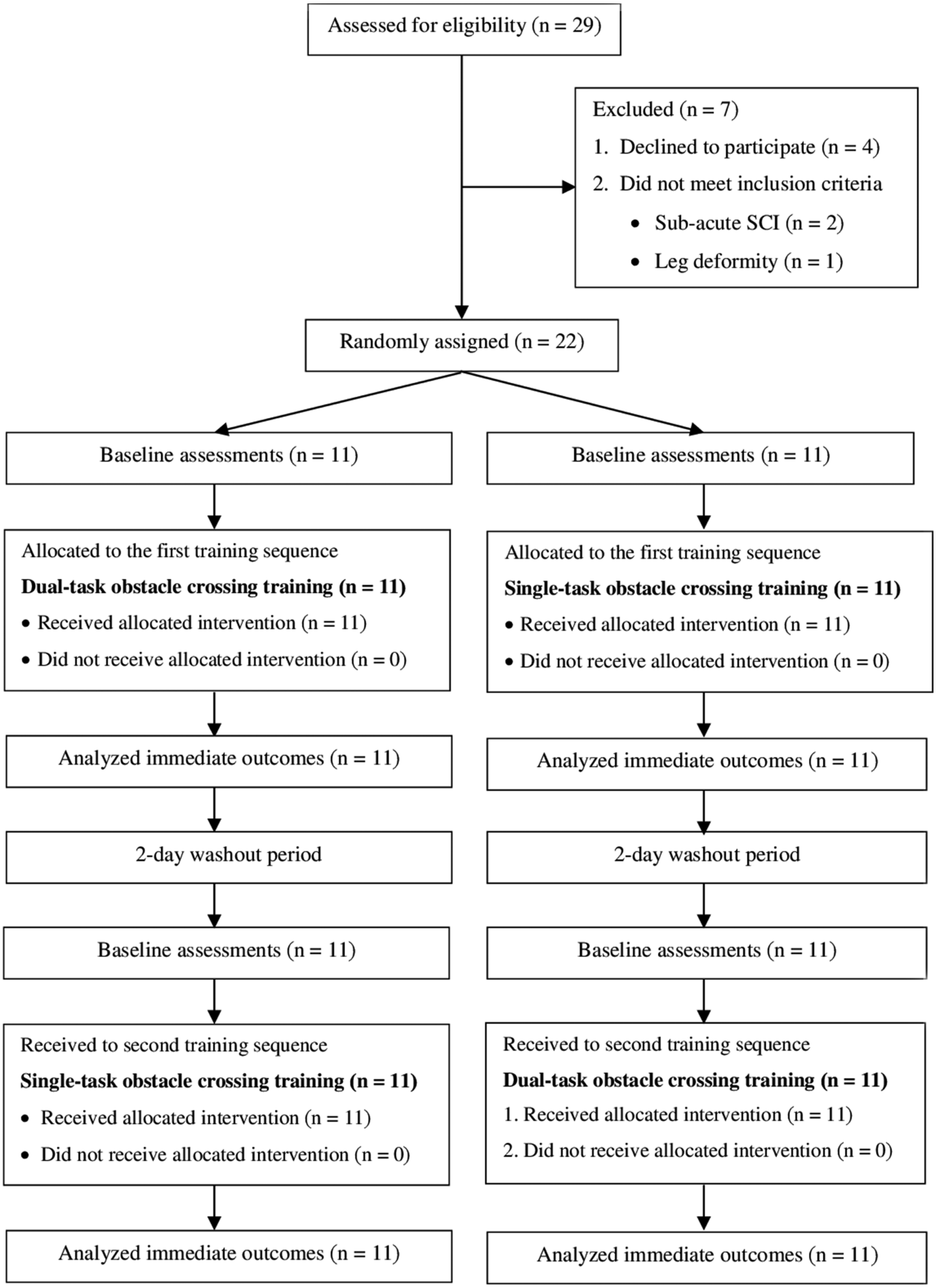

Figure 2. Participation flowchart.

Table 1. Participant characteristics

Variable	Findings ($N = 22$)
Age[a] (years)	49.81 ± 1.17 (44.44 – 55.17)
Gender: men/women (*n*)	16/6
Body mass index[a] (kg/m^2)	24.05 ± 3.27 (22.55 – 25.54)
Post injury time[a] (m)	60.86 ± 3.94 (42.89 – 78.82)
Cause of injury: nontraumatic/traumatic (*n*)	14/8
Severities of injury: AIS C/D (*n*)	5/17
Motor score[a,b]	86.14 ± 9.30 (81.90 – 90.37)
Sensory score[a,b]	99.47 ± 9.68 (95.07 – 103.88)
Level of injury: incomplete paraplegia/tetraplegia (*n*)	21/1
Type of devices used: none/cane/crutches/walker (*n*)	12/2/3/5

Note: AIS = American Spinal Injury Association (ASIA) Impairment Scale.

[a] The data are presented using mean ± *SD* (95% CI).

[b] Motor and sensory scores were derived from criteria from the ASIA protocols, with the total motor scores of 100 and sensory scores of 112.

cognitive errors (**Figure 3B**). Then the failure rates obviously decreased thereafter (**Figures 3A** and **3B**), especially for the Stroop task errors (from 47 trials to 14 trials; **Figure 3B**).

Outcomes of the study

There were no significant carryover effects for all outcome measures ($p > .10$) (**Table 2**). Therefore, the findings of both training sequences were used for data analyses. Participants showed significant improvement in all functional tests of both primary outcomes (10MWT and dual-task 10MWT) and secondary outcomes (TUG and FTSST) following both training programs (**Table 3**). However, this improvement was not significantly different between the training programs, except for the TUG, which was approaching significant differences ($p = .06$) (**Table 3**). Furthermore, the percent of Stroop task errors was significantly improved after the DTOC training ($p < .05$), but not after the STOC training ($p > .05$) (**Table 3**). This improvement showed a significant difference between the training programs ($p = .014$) (**Table 3**).

Discussion

The study compared the immediate effects following STOC and DTOC training on the functional and cognitive abilities necessary for daily living in ambulatory participants with SCI. The results indicate that participants with long post-injury time (approximately 5 years) were able to walk over an obstacle successfully with low failure rates while practicing STOC (**Figure 3A**). On the contrary, participants had high failure rates due to cognitive task (Stoop task errors) and physical task errors (leg or device contacting with the obstacle) during the DTOC (**Figure 3**). However, these failures obviously decreased within a 30-minute training session (**Figures 3A** and **3B**). Participants in both groups also showed significant improvement in all functional outcomes after the training ($p < .05$) (**Table 3**). However, the percent of Stroop task errors was significantly improved only after DTOC training, whereas obvious differences between the training programs were found for the percent of Stroop task errors and TUG (*p*s = .014 and .06) (**Table 3**).

Although the participants had intact cognitive functions, the sensorimotor deterioration following SCI might increase physical and attention demands needed to control a movement. Thus, they demonstrated a high rate of cognitive task errors (percent of Stroop task errors) at the beginning of their participation in the DTOC training program (**Figures 3A** and **3B**). This is important as a Stroop task is a less automated task (ie, naming color of the word) while inhibiting the interference arising from a more automated

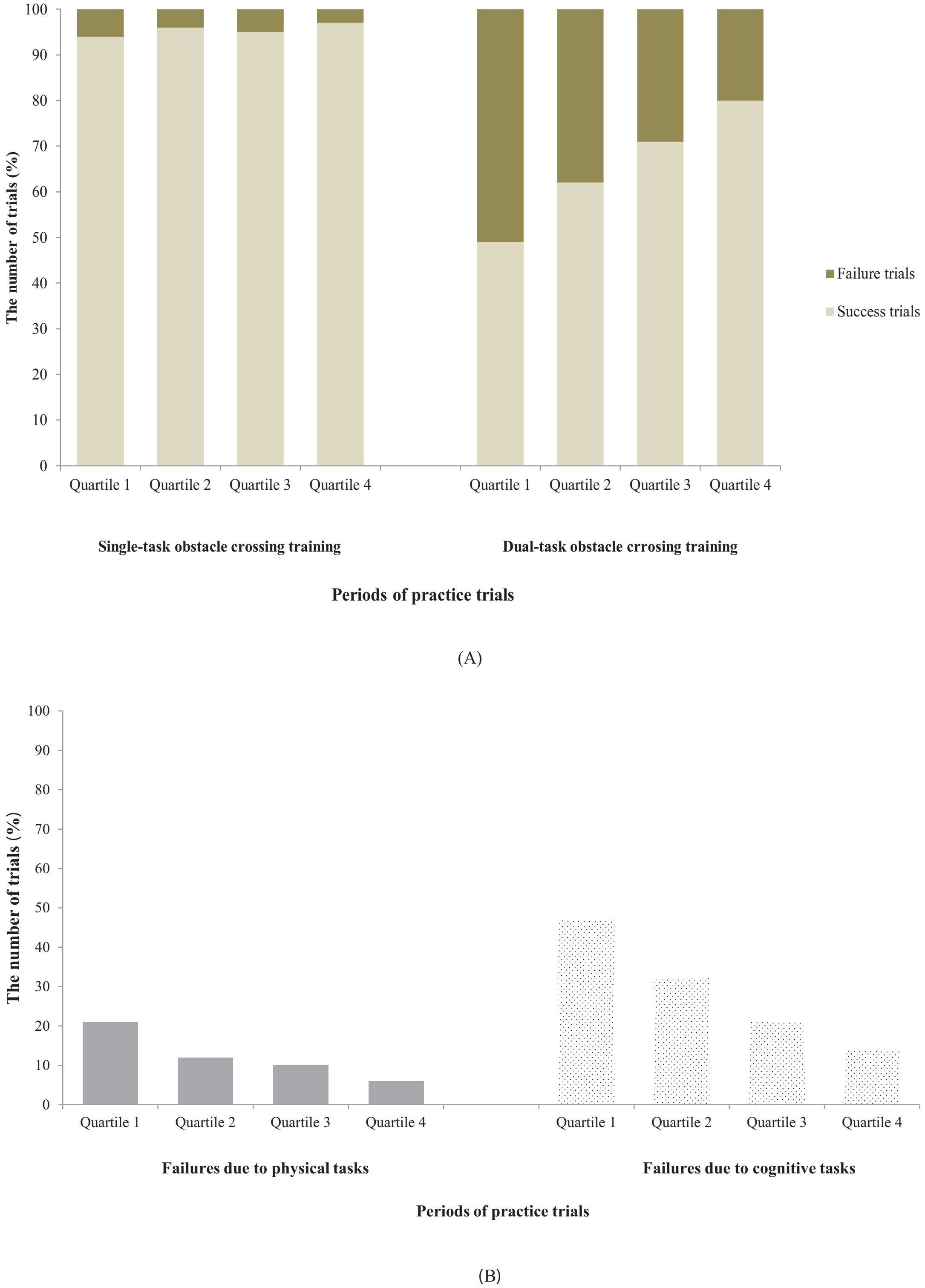

Figure 3. Proportion of the success and failure trials during participation in a 30-minute training program. (A) Proportion of the success and failure trials for single-task obstacle crossing and dual-task obstacle crossing. (B) Reasons of failures on dual-task obstacle crossing training.
Note: The total number of practice trials during 30-minute training period of each participant was converted to 100% and divided into four quarters (25%, X axis). Y axis represents the number of trials (%).

Table 2. Carryover effect analysis

Variable	S_{AB}	S_{BA}	*p*
Single-task 10-Meter Walk Test (m/s)	1.54 ± 0.48 (1.09 – 1.98)	1.59 ± 0.41 (1.21 – 1.96)	.83
Dual-task 10-Meter Walk Test (m/s)	1.49 ± 0.46 (1.06 – 1.91)	1.53 ± 0.40 (1.16 – 1.91)	.84
Percent of Stroop Color and Word Test task errors (%)	7.71 ± 11.67 (0.96 – 14.45)	9.14 ± 8.73 (4.09 – 14.18)	.72
Timed Up and Go Test (s)	27.80 ± 9.39 (19.11 – 36.50)	26.94 ± 10.45 (17.27 – 36.62)	.87
Five times sit-to-stand test (s)	22.12 ± 3.16 (19.20 – 25.03)	21.58 ± 2.07 (19.67 – 23.49)	.72

Note: The data are presented using mean ± *SD* (95% CI). Null hypothesis: $\gamma A = \gamma B$; where γA denoted carryover effects of intervention A (single-task obstacle crossing) and γB denoted carryover effects of intervention B (dual-task obstacle crossing). The hypothesis that $\gamma A = \gamma B$ was tested by comparing the mean sum of S_{AB} and the mean sum of S_{BA} using the independent samples t-test. $S_{AB} = X_{1,AB}+X_{2,AB}$ and $S_{BA} = X_{1,BA}+X_{2,BA}$, where $X_{i,AB}$ denoted the post-test outcomes of the measurement made in period i (1 or 2) on the participants who received the interventions in the order AB, and $X_{i,BA}$ denoted the same for participants who received interventions in the order BA.[9] The *p* value was analyzed using an independent sample *t* test ($\alpha > 0.10$).

task (ie, reading the word).[21,22] The difficulty in inhibiting the more automated process is called the Stroop effect.[22] Thus the color word Stroop task is widely used to reflect the ability to inhibit cognitive interference and multiple cognitive functions such as attention, processing speed, cognitive flexibility, and working memory.[22,23] The errors in color word Stroop task also potentially reflect deficits in the ability to perform dual-task activities that are commonly used to indicate the ability of task integration and coordination skills for mobility in a daily living,[24,25] and risk of fall of these individuals.[7,26, 27] Nonetheless, these failures could decrease after participation in a 30-minute DTOC training program (**Figure 3**). Thus the findings may suggest the clinical contribution of the DTOC program on mobility and fall risk reduction of these individuals.

The improvement of all functional outcomes immediately after both training programs ($p < .05$) (**Table 3**) confirms the challenging effects of obstacle crossing as reported previously.[9,28,29] However, the incorporation of dual-task training could further increase the task demands of obstacle training for ambulatory individuals with SCI, as it could clearly improve the outcomes of a complex motor task test (TUG) and percent of cognitive task errors after the training (**Table 3**). Previous studies reported that the ability to execute a dual task required individuals to switch, divide, or share attention capacity to simultaneously control physical and cognitive tasks. Such training task would facilitate a strong relationship between sensory information and motor tasks (information-action coupling) to produce an efficient movement.[3,30] Thus, repetitive practice in the DTOC posed a greater demand on postural and cognitive tasks than the STOC, helping the participants to improve a complex motor task and cognitive activity.[3] On the contrary, the 10MWT and FTSST were single-task tests that may be too simple to support the benefit of DTOC over the STOC for ambulatory individuals with SCI who mostly had mild lesion severity (AIS D, **Table 1**). Thus the outcomes of these tests showed no significant differences between the training programs. The present findings preliminarily suggest the superior effects of DTOC over the STOC training on a complex motor task test and cognitive activity of the ambulatory individuals with SCI. The further incorporation of balance assessments using multitask conditions, such as a cognitive TUG, might be a more sensitive indicator to reflect benefit of DTOC for these individuals.

Limitations

To the best of the researchers' knowledge, there was no intervention study on the effects of dual-task training in ambulatory individuals with

Table 3. Functional outcomes of the participants

Variable	Single-task obstacle crossing (STOC) training ($n = 22$)		Dual-task obstacle crossing (DTOC) training ($n = 22$)		Change scores[a] ($n = 22$)		p
	Pre-test	Post-test	Pre-test	Post-test	STOC training	DTOC training	
Single-task 10-Meter Walk Test (m/s)[b]	0.65 ± 0.26 (0.54 – 0.77)	0.69 ± 0.26* (0.57 – 0.80)	0.67 ± 0.24 (0.56 – 0.78)	0.70 ± 0.24* (0.59 – 0.81)	0.04 ± 0.05 (0.01 – 0.06)	0.03 ± 0.05 (0.01 – 0.06)	.66
Dual-task 10-Meter Walk Test (m/s)[b]	0.58 ± 0.24 (0.47 – 0.69)	0.65 ± 0.25* (0.53 – 0.76)	0.61 ± 0.22 (0.51 – 0.71)	0.67 ± 0.23* (0.56 – 0.77)	0.06 ± 0.07 (0.02 – 0.09)	0.05 ± 0.06 (0.02 – 0.08)	.73
Percent of Stroop Color and Word Test task errors (%)[c]	9.55 ± 15.82 (2.53 - 16.57)	7.09 ± 14.44 (0.69 - 13.50)	10.75 ± 13.01 (4.97 - 16.52)	2.55 ± 7.63* (-0.82 - 5.94)	-2.45 ± 9.06 (-6.47 - 1.56)	-8.19 ± 10.90 (-13.02 – (-3.36))	.014*
Timed Up and Go Test (s)[c]	18.12 ± 8.01 (14.56 – 21.67)	16.41 ± 6.63** (13.47 – 19.35)	18.38 ± 8.44 (14.63 – 22.12)	15.98 ± 6.69** (13.01 – 18.95)	1.70 ± 2.63 (0.54 – 2.87)	2.40 ± 2.92 (1.11 – 3.69)	.06
Five times sit-to-stand test (s)[c]	13.26 ± 3.96 (11.51 – 15.02)	11.93 ± 4.26** (10.04 – 13.82)	13.46 ± 4.12 (11.63 – 15.29)	11.67 ± 3.22** (10.23 – 13.10)	1.33 ± 1.25 (0.77 – 1.89)	1.79 ± 1.57 (1.10 – 2.49)	.53

Note: DTOC = dual-task obstacle crossing; STOC = single-task obstacle crossing.

[a] Change scores were the differences between pre- and post-training of each training program.

[b] The data are presented using mean ± *SD* (95% CI). The differences between pre- and post-test were analyzed using the dependent sample *t* test, and the differences of change scores were investigated using the independent sample *t* test.

[c] The data are presented using the median (interquartile range). The differences between pre- and post-test were analyzed using the Wilcoxon signed-rank test, and the differences of change were analyzed using the Mann–Whitney *U* test.

$^{*}p < 0.5$. $^{**}p < .001$.

SCI. Therefore, the outcomes of this study were assessed immediately after the training primarily to report the effects of dual-task training for these individuals. In addition, the study recruited only participants with chronic SCI to minimize effects of spontaneous recovery on the outcomes of a crossover design study. Furthermore, the high demands of both physical and cognitive task training limited participation to persons with mild lesion severity (AIS D, 77%) and incomplete paraplegia (95%). Nonetheless, these individuals were less likely to change after any treatments and were at a greater risk of multiple falls, particularly those who had rather good functional ability.[31,32] Therefore the present findings suggest the superior effects of DTOC over the STOC training on mobility and ability relating to risk of falls. Nonetheless, they may limit the clinical implication for those with AIS C and incomplete tetraplegia.

Future studies

A further intervention study in participants with various SCI characteristics and the incorporation of more complex or multitask tests such as the cognitive TUG and fall monitoring would clearly confirm the effects of dual-task training in ambulatory individuals with SCI.

Conclusion

Obstacle crossing is very demanding, thus it significantly improved functional ability of ambulatory individuals with SCI immediately after training. However, the incorporation of dual-task training with obstacle crossing training could further enhance the benefit of the training task on a complex motor activity and cognitive function. The findings are clinically important as they were evidenced in participants who were less capable to change according to any treatments (approximately 5 years post-injury). Thus the incorporation of dual-task training might promote rehabilitation outcomes for these individuals.

Conflicts of Interest

The authors declare no conflicts of interest.

REFERENCES

1. Patla AE, Shumway-Cook A. Dimensions of mobility: Defining the complexity and difficulty associated with community mobility. *J Aging Phys Act.* 2010;7(1):1-19.
2. Plummer-D'Amato P, Kyvelidou A, Sternad D, Najafi B, Villalobos RM, Zurakowski D. Training dual-task walking in community-dwelling adults within 1 year of stroke: A protocol for a single-blind randomized controlled trial. *BMC Neurol.* 2012;12(1):129.
3. Agmon M, Belza B, Nguyen HQ, Logsdon RG, Kelly VE. A systematic review of interventions conducted in clinical or community settings to improve dual-task postural control in older adults. *Clin Interv Aging.* 2014;9(1):477-492.
4. Fritz NE, Cheek FM, Nichols-Larsen DS. Motor-cognitive dual-task training in persons with neurologic disorders: A systematic review. *J Neurol Phys Ther.* 2015;39(3):142-153.
5. Wang XQ, Pi YL, Chen BL, et al. Cognitive motor interference for gait and balance in stroke: A systematic review and meta-analysis. *Eur J Neurol.* 2015;22(3):555-e37.
6. Wang XQ, Pi YL, Chen BL, Wang R, Li X, Chen PJ. Cognitive motor intervention for gait and balance in Parkinson's disease: Systematic review and meta-analysis. *Clin Rehabil.* 2016;30(2):134-144.
7. Lajoie Y, Barbeau H, Hamelin M. Attentional requirements of walking in spinal cord injured patients compared to normal subjects. *Spinal Cord.* 1999;37(4):245-250.
8. Srisim K, Thaweewannakij T, Arrayawichanon P, Amatachaya P, Mato L, Amatachaya S. Effects of dual- and complex-task on walking ability of ambulatory individuals with spinal cord injury. *Eur J Phys Rehabil Med.* 2017;53(6):920-927.
9. Pramodhyakul W, Wattanapan P, Siritaratiwat W, Eungpinichpong W, Amatachaya S. Immediate effects of obstacle crossing training in independent ambulatory patients with spinal cord injury. *Spinal Cord.* 2013;51(5):379-383.
10. Grabiner MD, Troy KL. Attention demanding tasks during treadmill walking reduce step width variability in young adults. *J Neuroeng Rehabil.* 2005;2(1):3-6.
11. van Hedel HJ, Dietz V, Curt A. Assessment of walking speed and distance in subjects with an incomplete spinal cord injury. *Neurorehabil Neural Repair.* 2007;21(4):295-301.
12. Lam T, Noonan V, Eng J. A systematic review of functional ambulation outcome measures in spinal cord injury. *Spinal Cord.* 2008;46(1):246-254.
13. Poncumhak P, Saengsuwan J, Amatachaya S. Ability of walking without a walking device in patients with

spinal cord injury as determined using data from functional tests. *J Spinal Cord Med.* 2014;37(4): 389-396.

14. Poncumhak P, Saengsuwan J, Kamruecha W, Amatachaya S. Reliability and validity of three functional tests in ambulatory patients with spinal cord injury. *Spinal Cord.* 2013;51:214-217.
15. Finch E, Brooks D, Stratford P, Mayo N. *Physical Rehabilitation Outcome Measures: A Guide to Enhanced Clinical Decision Making*. 2nd ed. Hamilton: BC Decker; 2002.
16. Ikeda Y, Okuzumi H, Kokubun M. Dual task performance of the Stroop color-word test and stepping in place. *Motor Control.* 2014;18(1):76-87.
17. Phonthee S, Saengsuwan J, Amatachaya S. Falls in independent ambulatory patients with spinal cord injury: Incidence, associated factors and levels of ability. *Spinal Cord.* 2013;51(5):365-368.
18. Whitney SL, Wrisley DM, Marchetti GF, Gee MA, Redfern MS, Furman JM. Clinical measurement of sit-to-stand performance in people with balance disorders: Validity of data for the five-times-sit-to-stand test. *Phys Ther.* 2005;85(10):1034-1045.
19. Eriksrud O, Bohannon RW. Relationship of knee extension force to independence in sit-to-stand performance in patients receiving acute rehabilitation. *Phys Ther.* 2003;83(6):544-551.
20. Grizzle J. The two-period change-over design and its use in clinical trials. *Biometrics.* 1965;21:467-481.
21. MacLeod CM, Dunbar K. Training and Stroop-like interference: Evidence for a continuum of automaticity. *J Exp Psychol Learn Mem Cogn.* 1988;14:126-135.
22. Scarpina F, Tagini S. The Stroop Color and Word Test. *Front Psychol.* 2017;8:557.
23. Kane MJ, Engle RW. Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *J Exp Psychol Gen.* 2003;132:47-70.
24. Smith E, Cusack T, Blake C. The effect of a dual task on gait speed in community dwelling older adults: A systematic review and meta-analysis. *Gait Posture.* 2016; 44(1):250-258.
25. Ruthruff E, Van Selst M, Johnston JC, Remington R. How does practice reduce dual-task interference: Integration, automatization, or just stage-shortening? *Psychol Res.* 2006;70(2):125-142.
26. Dietz V, Fouad K. Restoration of sensorimotor functions after spinal cord injury. *Brain.* 2014;137(Pt 3):654-667.
27. Muir-Hunter SW, Wittwer JE. Dual-task testing to predict falls in community-dwelling older adults: A systematic review. *Physiotherapy.* 2016;102(1):29-40.
28. Said C, Goldie P, Patla A, Sparrow W, Martin K. Obstacle crossing in subjects with stroke. *Arch Phys Med Rehabil.* 1999;80(9):1054-1059.
29. Huang SC, Lu TW, Chen HL, Wang TM, Chou LS. Age and height effects on the center of mass and center of pressure inclination angles during obstacle-crossing. *Med Eng Phys.* 2008;30(8):968-975.
30. Silsupadol P, Shumway-Cook A, Lugade V, et al. Effects of single-task versus dual-task training on balance performance in older adults: A double-blind, randomized controlled trial. *Arch Phys Med Rehabil.* 2009;90(3):381-387.
31. Phonthee S, Saengsuwan J, Amatachaya S. Falls in independent ambulatory patients with spinal cord injury: Incidence, associated factors and levels of ability. *Spinal Cord.* 2013;51(5):365-368.
32. Srisim K, Saengsuwan J, Amatachaya S. Functional assessments for predicting a risk of multiple falls in independent ambulatory patients with spinal cord injury. *J Spinal Cord Med.* 2015;38(4):439-445.